NONDESTRUCTIVE EVALUATION OF COMPOSITE MATERIALS WITH BACKSCATTERING MEASUREMENTS

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ABSTRACT

Initial experiments have been performed to characterize the scattering of acoustic waves from glass/epoxy and graphite/epoxy composite panels. Experiments were conducted in the region $0.1 \le ka \le 1.0$ on both types of fiber reinforced composites. The data clearly show that a maximum in the backscattering ultrasonic energy occurs for orientations which place the fiber axis perpendicular to the propagation vector.

INTRODUCTION

The propagation of elastic wave through fiber reinforced composite is a very complex process. As it travels through the material, the acoustic wave is dramatically affected by the anisotropic nature of the layered composite. Significant changes also result from the multiple scattering events that occur because of the myriad of stiff fibers in a soft plastic matrix. Only recently have theoretical and experimental studies begun to unravel the subtleties of the acoustic wave/composite interaction.

The objective of this research work has to study the multiple scattering phenomena in fiber reinforced composites, as revealed by backscattering measurements.

RESULTS AND DISCUSSION

An experimental apparatus was built to permit rotating test specimen while maintaining a constant angle of incidence. By varying the fiber diameter and the frequency of the incident wave, tests were conducted in the pseudo-Rayleigh scattering range $0.1 \le ka \le 1.0$, where k is the wave number and a is the fiber diameter. The composite materials examined were graphite/epoxy and glass/epoxy. A schematic of the experimental set-up and nomenclature are shown in Fig. 1. Measurements of backscattering were averaged over 32 points on the specimen for a constant incident angle. As expected, the backscattering (scattering detected by the sending transducer) is maximum for orientations that place the fibers in a specific ply perpendicular to the ultrasonic beam, (see Fib. 2). Also shown in Fig. 2 is the effect of surface roughness which contributed about 1 dB to the backscattered energy. This can be nearly eliminated by polishing the specimen surface. In Fig. 3 a schematic diagram is shown as a guide in determining fiber angle in a quazi-isotropic laminate. Using this simple convention then Figs. 4 and 5 demonstrate the ease of using backscattering information to determine ply orientation.

The width of the backscattering peak is affected by both the beam divergence and the uniformity of fiber alignment. If beam divergence is constant, then the peak width may be used to estimate the amount of waviness in an otherwise parallel row of fibers. To demonstrate this, a sample with a 30^{o} misalignment was fabricated. The effect of this misalignment is shown along with perfectly aligned sample in Fig. 6. The increased bandwidth was capable of determining misalignment to an accuracy of $\pm 1^{o}$ of arc. This is shown in Fig. 7, where the actual angle versus the calculated misalignment angles are plotted.

Backscattering is observed whenever a discontinuity is encountered by the acoustic. Defects such as a porosity with spherical symmetry, result in a uniform increase of scattering over wide angles as shown in Fig. 8.

It is concluded that backscattering measurements may be used to determine fibers orientation, misalignment and in some cases the presence of porosity. Further work is underway to quantify the angular dependence and intensity of backscattering in composite materials.

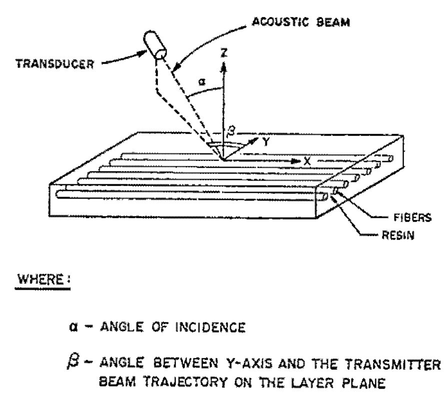

Fig. 1. Schematic representation of experimental set-up used to measure backscattering from composite samples.

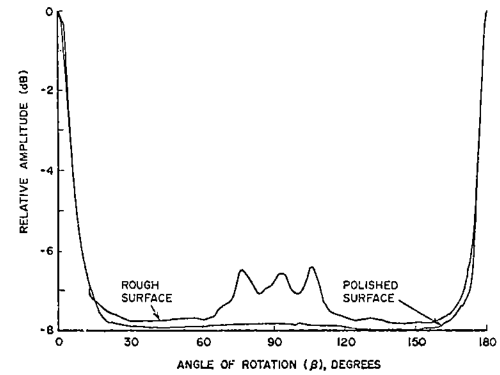

Fig 2 Backscattering from unidirectional ($[0]_8$)Gl/Ep composite for a 30° angle of incidence. The effect of surface roughness is also shown.

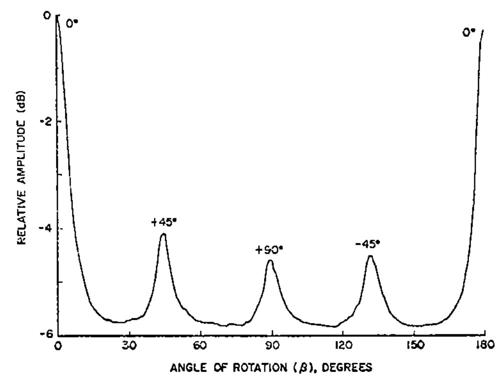

Fig 4 Backscattering from a quazi-isotropic ($[0, \pm45, 90]_S$) composite for a 30° angle of incidence. Scattering from each ply is apparent (see Figure 3).

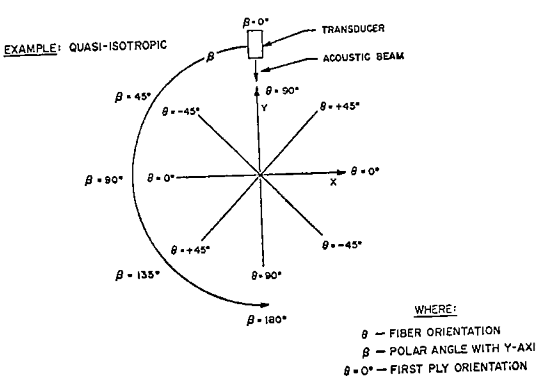

Fig. 3 Angular convention used to determine fiber orientation in backscattering experiments.

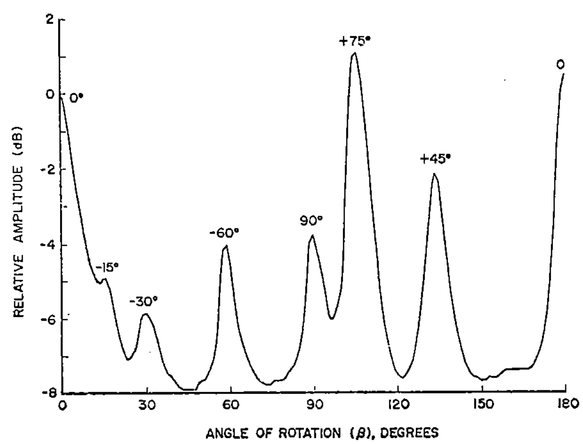

Fig. 5 Backscattering from graphite/epoxy composite $[0^{\circ}, -15^{\circ}, -30^{\circ}, +45^{\circ}, -60^{\circ}, +75^{\circ}, 90^{\circ}]_S$. Angle of incidence was 40°.

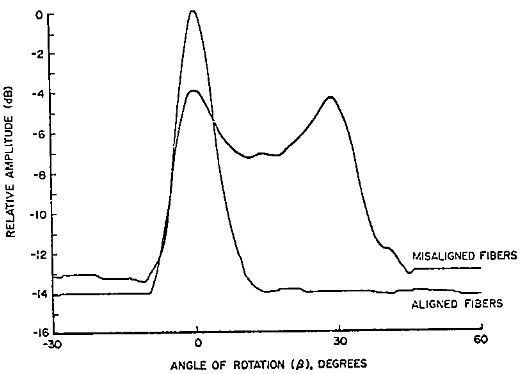

Fig. 6 The effect of misalignment on back-scattering from single-ply glass/epoxy material.

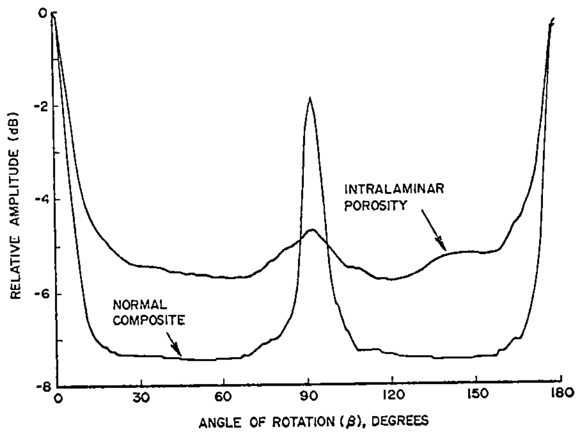

Fig. 8 Backscattering from $[0,90]_{2S}$ glass/epoxy composite both with and without porosity. Glass micro-balloons were used to simulate porosity.

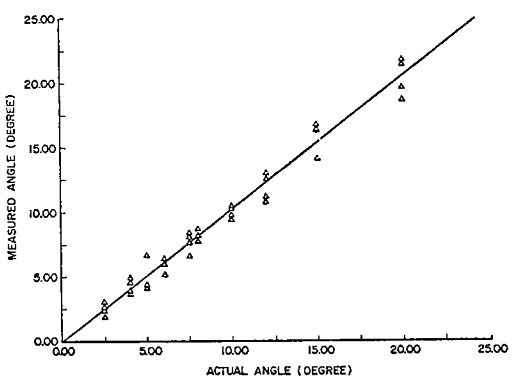

Fig. 7 Comparison of measured and actual fiber misalignment in glass/epoxy composite material.